

DIFFRACTIVE DIS AND SOFT COLOUR INTERACTIONS

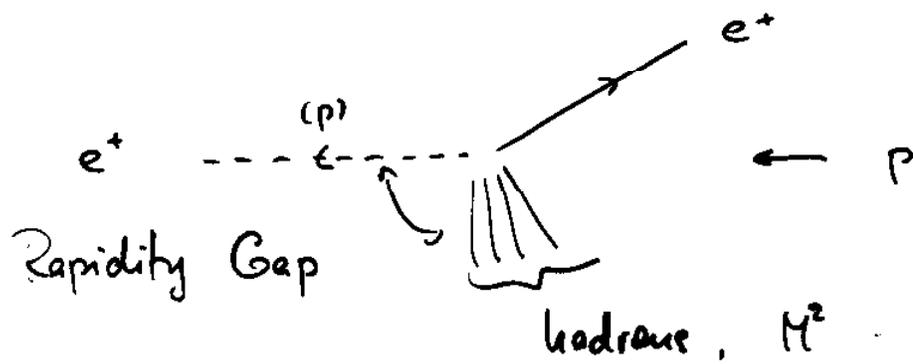
with A. Hebecker, M. McDermott

NP '96, '97; in preparation

- Soft colour interactions
- High- P_{\perp} jets
- Relation to other approaches

(1) Soft colour interactions

rapidity gap events: $\sim 10\%$ of DIS final states at small x are unusual:



observation: $\sigma_D/\sigma_{ind} \approx F_2^D/F_2 \approx \text{const.}$,
independent of Q^2 , jets in final state!

natural interpretation of RGEs: colour neutral part of proton is stripped off and fragments into hadrons independent of proton remnant \rightarrow interplay between soft and hard interactions!

Systematic treatment in QCD?

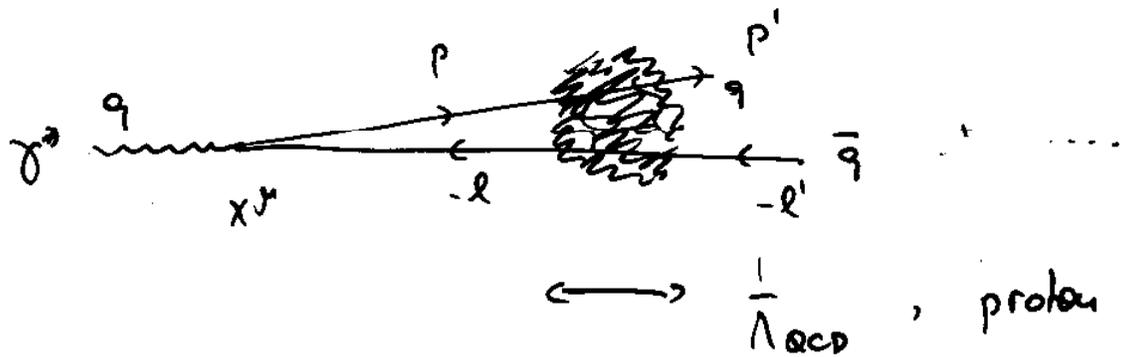
perturbative expansion in powers of α_s is

problematic; attempt: high-energy expansion

in proton rest frame

- Semiclassical approach

basic idea: production of a fast quark-antiquark pair (+ radiation ...) in a 'soft' colour field, representing a state with high density of gluons



cf. ..., B_j , H , ...

addendum:

(i) treat proton as source of 'soft' colour; elastic q -, \bar{q} -, g - scatterings can then be calculated

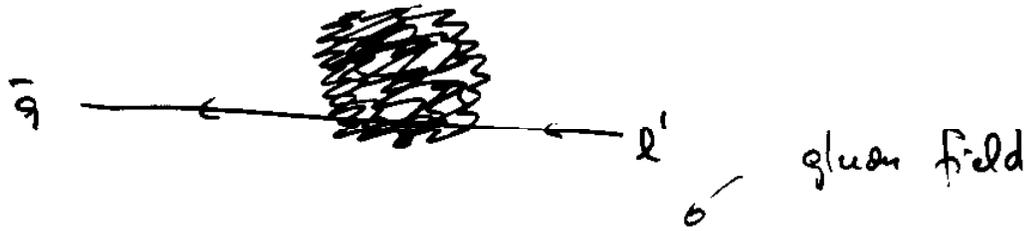
(ii) $(q\bar{q} \dots)$ in colour singlet \rightarrow diffractive DIS

$(q\bar{q} \dots)$ with arbitrary colour \rightarrow inclusive DIS

no further ad hoc-assumptions!

- High energy expansion
elastic \bar{q} -scattering:

cf. Bjorken, Kogut, Soper
Nudtman 1981



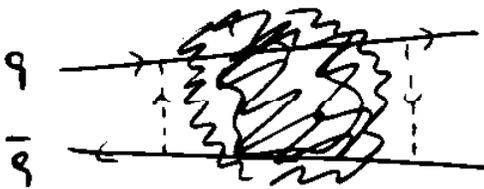
$$\Psi_\sigma(x) = \Psi_\sigma^{(0)}(x) - \int_{x_1} S_F(x-x') \mathcal{B}(x') \Psi_\sigma(x')$$

$$= e^{i\ell'x} (U_\sigma(x) + \dots) \sigma(\ell')$$

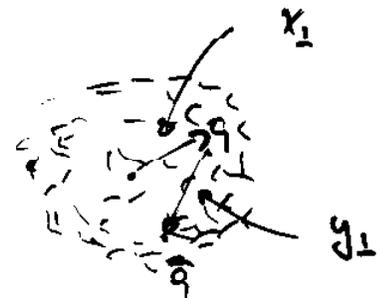
$$U_\sigma(x) = P \exp \left(i \int_{x_1}^{\infty} dx'_1 G_-(x'_1, x_-, x_1) \right)$$

all diffractive and inclusive cross sections can
be expressed in terms of one non-pert. quantity:

$$\text{tr } W_{x_1}(y_\perp)$$



closed Wilson loop



transverse plane

$$W_{x_1}(y_\perp) = \bar{F}^\dagger(x_\perp) \bar{F}(x_\perp + y_\perp) - 1, \quad \bar{F}(x_\perp) = U_\sigma(x) |_{x_1 \rightarrow -\infty}$$

short distance expansion:

$$\int_{x_2} \text{tr } W_{x_1}(y_2) = -\frac{1}{2} y_2^2 C_1 + O(y_2^4)$$

- inclusive structure function ($q\bar{q}$)

$$F_T(x, Q^2) \propto \int_x^1 \frac{d\beta}{\beta} \left(\beta(1-\beta)^2 \left(\ln \frac{Q^2}{\Lambda^2} - 1 \right) C_1 + f(\beta) \right)$$

identical with photon-gluon fusion, where

$$C_1 = 2\bar{u}^2 \alpha_s \times g(x)$$

i.e., gluon density of classical bremsstrahlung spectrum

- diffractive structure function ($q\bar{q}$)

amplitude $\propto \text{tr } W_{x_1}(y)$ (projection on colour singlet final state) \rightarrow no contribution from large l_2^+ ; relevant domain:

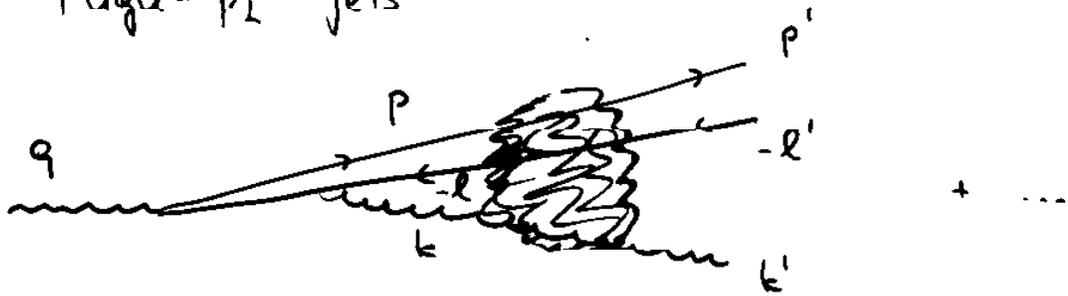
$$l_2^+ \sim \Lambda^2, \quad \alpha \sim \frac{\Lambda^2}{Q^2} \quad (\alpha = l_2^+ / q_+)$$

$$F_T^D(x, Q^2, \xi) \propto \frac{\beta}{\xi} F(\beta) \quad \begin{matrix} x = \beta \xi, \beta = \frac{Q^2}{Q^2 + \xi} \\ \text{use - perturbative} \end{matrix}$$

Bjorken, Cooper '73, AJPT

cf. 'soft pomeron'

(2) High- p_T jets



high- p_T quark jets : $p_T \sim l_T \gg k_T \geq \Lambda$

momentum transfer :

$$p_T'' \equiv p_T' - p_T \quad , \quad \Delta_1 = p_T' + k_T' + l_T' - p_T - k_T - l_T$$

↑ quark
 ↑ proton

colour structure :

$$T \propto \int \frac{d^4 p_T}{(2\pi)^4} C_{\alpha\beta}^a T_{\beta\alpha}^a$$

$$\propto \int d^4 x_1 e^{-i x_1 \Delta_1} \text{tr} [W_{x_1}^{\Delta_1}(k_1 - k_1')] ,$$

$$W_{x_1}^{\Delta_1}(y_2) = \frac{1}{4} \left(\text{tr} (F^{\dagger}(x_2) F(x_2 + y_2)) - 1 \right)$$

completely analogous to $q\bar{q}$ - production !

$q\bar{q}$ pair acts as colour dipole, slow gluon

instead of slow quark :

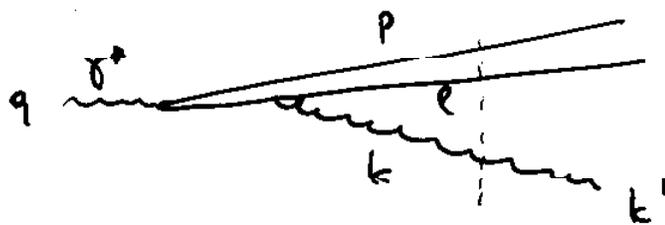
$$k_T' \sim \Lambda ; \quad \alpha' \sim \frac{\Lambda^2}{Q^2} , \quad \alpha' \equiv k_T' / q_T$$

process corresponds to photon-gluon fusion in
 Breit-frame, with diffractive gluon density:

→ Hebecker

diffractive parton densities: Berera, Sopu; Collins...
 Trentadue, Venetiano

proton rest frame:

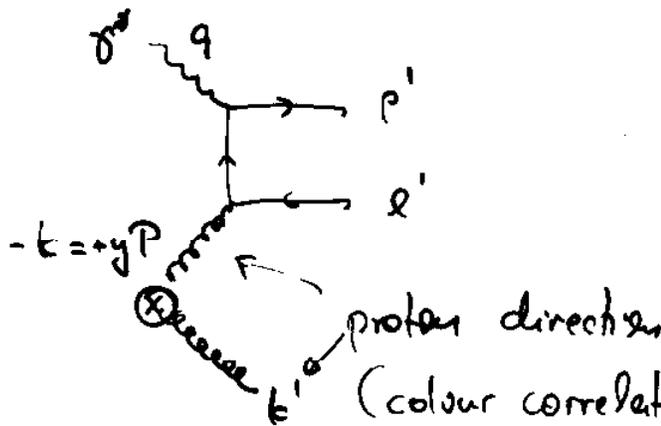


$$q_0 = \frac{Q^2}{2ux}$$

$$k_+ \sim \Lambda, \quad k_+ = d'q_+ \sim \frac{\Lambda}{x} \gg \Lambda,$$

large $k_- = q_- - p_- - l_- = -\frac{Q^2 k_+^2}{2q_0} \sim -\Lambda x, \quad k_-^2 \sim -\Lambda^2$
 small

Breit frame:



$$q^\mu = (0, \vec{0}, Q)$$

$$x \leq y \leq \bar{y} = \frac{x}{\beta}$$

small

Λ^2

(RG!)

contribution to structure function:

$$\tilde{F}_2^D(x, Q^2, \xi) \sim \frac{d\sigma_T}{d\xi} = \int_x^\xi dy \sigma_T(y) \frac{df_g(y, \xi)}{d\xi}$$

boson-gluon fusion

$$\frac{df_g(y, \xi)}{d\xi} = \frac{1}{9\xi} \frac{b}{1-b} \int \frac{d^2k_1}{(2\pi)^2} (k_1^\mu)^2 \int_{x_1} \left| \int \frac{d^2k_2}{(2\pi)^2} \frac{d^4 \Gamma_{\mu\nu}^{\lambda\sigma}(k_1, k_2) k_{1\nu} k_{2\sigma}}{k_1^2 k_2^2 (1-b)} \right|^2$$

$b = \frac{y}{\xi}$

y : momentum fraction of gluon in proton!

— Comparison with $q\bar{q}$ -final state



$$\left. \frac{d\sigma_T}{d\xi dp_1^2 dt} \right|_{t=0} \propto C_1^2 \frac{(\alpha(1-\alpha))^2 (\alpha^2 + (1-\alpha)^2) Q^2 p_1^2}{(\alpha(1-\alpha) Q^2 + p_1^2)^2}$$

with $C_1 \propto \alpha_s \times g(x)$ identical to prediction of 2-gluon models in leading order!

- Task of semiclassical approach

(i) P_L - spectrum of boson-gluon fusion

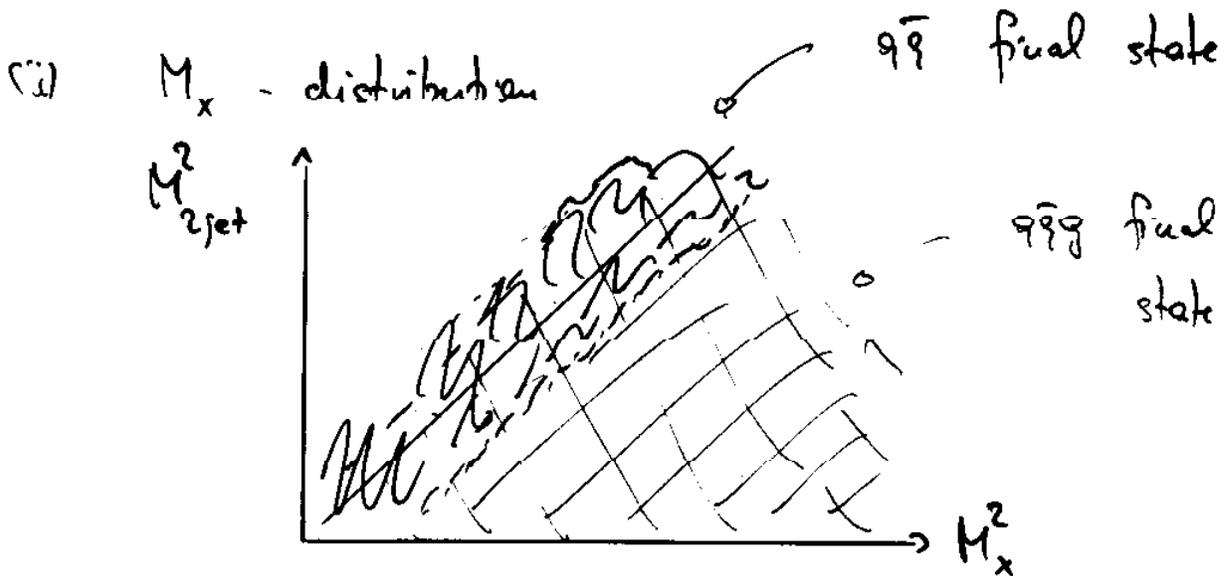
$$\frac{d\sigma_T}{d\alpha dp_L^2} \propto d_s \ln \frac{1}{x} h_* \frac{(\alpha^2 + (1-\alpha)^2) (\alpha(1-\alpha)^2 Q^2 + P_L^2)}{(\alpha(1-\alpha) Q^2 + P_L^2)^4}$$

\uparrow
 large colour factor

$P_L^2 > Q^2$: $\frac{d\sigma_T}{d\alpha dp_L^2} \propto \frac{1}{P_L^4}$

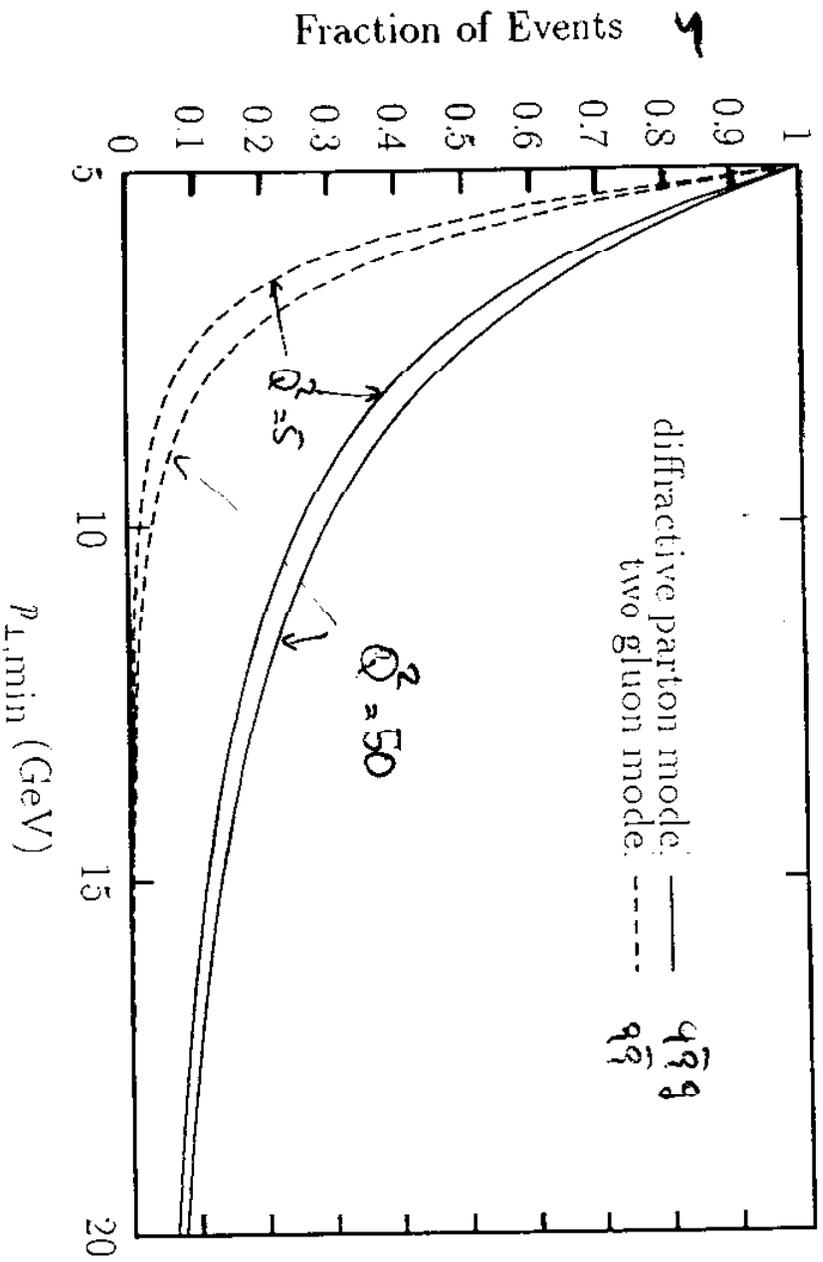
for comparison, $q\bar{q}$ final state (of 2-gluon mode)

$$\frac{d\sigma_T}{d\alpha dp_L^2} \propto \frac{Q^4}{P_L^{10}}$$



(iii) large enhancement by $\ln \frac{1}{x} h_*$

boson-gluon fusion process likely to be dominant
 since \ln order of $\ln \frac{1}{x} h_*$



$$f = \frac{N(p_{T1} > p_{T,min})}{N(p_{T1} > 5)}$$

(3) Relations to other approaches

- 'soft' pomeron models
phenomenology similar for gluonic pomeron;
pomeron flux factor, ξ - and t -dependence?
- 'hard' pomeron models (2-gluon exchange, ...)
Mueller; Ryskin; Nikolaev, Zakharov; Bartels, Levin,
Weizsäcker, ...
 p_L -spectrum qualitatively different; also
 M_T -distribution; higher orders?
- boson-gluon fusion 195 (with 'colour rotation')
same hard process, 'soft' colour interactions
crucial, but different M_T -distribution ($q\bar{q}g$)
- SCT à la Edin, Ingelman, Rattusman
same idea, different realization (MC)
- aliqued-jet model
Bjorken; Abramowicz, Frankfurt, Stenlund; ...
similar qualitative picture, asymmetric configurations
follow from colour singlet projection, but
... .. (050)

RESULTS + OPEN PROBLEMS

- Semiclassical approach leads to factorization of 'hard' and 'soft' processes (higher orders, evolution equations for diffractive parton densities):
- Crucial tests: hard p_2 -spectrum of boson-gluon fusion, M_x -distribution
- Open questions: ξ -dependence, role of further radiation in initial state?
- Relation between ordinary and diffractive parton densities ($g(x)$ & $df_g(y, \xi)/d\xi$?) would yield 'perfect' phenomenology)
- Non-perturbative evaluation of diffractive parton densities, i.e. $\int \mathcal{D}\mathcal{B} \frac{df}{d\xi}(y, \xi; W(\mathcal{B})) \Phi_{\mathcal{P}}$